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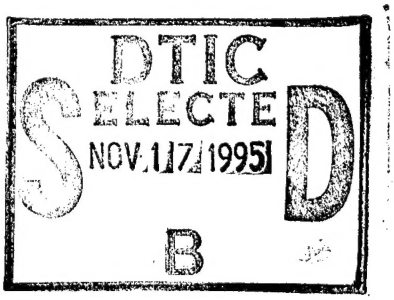

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This paper summarizes progress achieved during the first year of a three year project to determine the optimum technique factors for conventional mammography. This first year's work centered on establishing the contrast properties of mammography films and in assessing the current status of mammography system performance with regard to exposure times, film optical densities, and breast average glandular doses as breast thickness and composition is varied. This was done by compiling data collected on 177 medical physics surveys of mammography units in Colorado and by conducting more detailed testing on a single state-of-the-art mammography unit at the University of Colorado Health Sciences Center. Results indicate that the properties of essentially all mammography films, combined with the inadequate automatic exposure control performance of at least 30% of current mammography units, yield mammograms with suboptimal contrast for the detection of breast cancer, especially in thicker and denser breasts.

breast imaging technology
mammography, image quality
mammography, breast doses

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FOREWORD

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R E Hendrick 9/11/95

PI - Signature Date

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INTRODUCTION

Screening mammography trials have shown that mammography has a sensitivity to breast cancer ranging from 60% to 90%, with a trend toward lower sensitivity in premenopausal women [1,2]. In an analysis of "missed" breast cancers, Bird, et.al. determined that missed breast cancers are more likely to occur in radiographically dense breasts [3]. It is known that radiographically dense breasts have a greater probability of masking breast cancers, when they are present, due to the similar x-ray attenuation properties of glandular tissues and breast cancers. The higher the proportion of glandular tissues in the breast, the greater the probability that a breast cancer will be superimposed by normal glandular tissues and, therefore, missed in the mammogram.

We hypothesized that two technical factors contribute to the lower sensitivity of film-screen mammography to breast cancer in thicker, denser breasts. The first technical factor is the contrast properties of film used in film-screen mammography. Film-screen mammography presents fibroglandular tissues of the breast at lower optical densities than other tissues on mammograms. Because of the specific manner in which film translates x-ray or light exposure into optical densities, image contrast is lower in regions of film that are exposed to lower optical densities. Because of the heterogeneities in most breasts, fibroglandular tissues are presented at lower optical densities than other breast tissues. These lower optical densities result in a loss of contrast in fibroglandular tissues, the tissues of the breast that give rise to breast cancer and within which early breast cancer is most likely to be detected. The lower optical densities and reduced contrast within fibroglandular tissues may result in images in which breast cancer is completely masked or, if visible, may reduce the radiologist's confidence that a breast cancer is present.

We conjectured, based on preliminary data, that the second technical factor contributing to lower contrast in thicker, denser breasts is the performance of automatic exposure control (AEC) systems on most existing mammography units. More specifically, the performance of most AEC systems was believed to yield lower average optical densities for thicker, denser breasts. This would yield even lower densities in the glandular portion of a typical heterogeneous breast.

The first year's work on this research project was directed at evaluating the validity of these two hypotheses, collecting data on the variations in optical densities, image quality and dose that exist in the practice of mammography, and quantitating the loss of image quality that exists in actual practice. These data would then be used to determine optimal technique factors, in terms of target-filter, kVp, optical density, and exposure time selection, for film-screen mammography. This work was carried out almost entirely by Dr. Carmine Plott, the postdoctoral fellow who is supported by this grant.

BODY OF REPORT

This report consists of four subsections:

1. evaluation of film contrast properties
2. evaluation of mammography system performance
3. evaluation of dose and contrast properties of a single film-screen mammography system
4. future work to be performed

1. Evaluation of film contrast properties

The hypothesis that the specific properties of film are in part responsible for the lower sensitivity of film-screen mammography to breast cancer was evaluated by assessing the characteristic Hurter and Driffield (H&D) curves and gamma plots (or contrast plots) for seven different films used for mammography:

Film Type	Processing Time
Agfa MR5	Standard
Dupont Microvision	Standard and Extended
Fuji UM-MA	Standard
Fuji UM-MH	Standard
Kodak MRE-1	Extended
Kodak MRH-1	Standard
Kodak MRM-1	Standard

These films were processed under "optimized processing conditions" in terms of time, temperature, and chemistry as specified by the film manufacturers. Five films were processed using a 90 second "standard" processing time, Kodak MRE-1 was processed using 180 second "extended" processing, and Dupont Microvision was processed under both standard and extended conditions.

The resulting H&D curves for all eight film-processing combinations are shown in **Figure 1**. The gamma plots, constructed by plotting the point-to-point slope of the H&D curves versus average optical density of the two points, is shown in **Figure 2**. The gamma or contrast plots provide a clear depiction of the contrast produced by each film as a function of optical density. The linear part of the H&D curve would be represented by a flat line, parallel to the x- (optical density-) axis, on the gamma plot. The height of the curves of the gamma plot represents the amount of contrast present at each optical density.

Figure 2 shows several interesting features. First, it shows that there is a substantial variation in the amount of contrast produced by different films. Second, it shows that some films, such as Microvision and, to a lesser extent, MRE-1, have broader ranges of optical densities over which contrast is preserved, while others, such as MRH-1, MRM-1, UM-MA, and UM-MH, have relatively narrow ranges over which optimal contrast is preserved. This is reflective of a limited linear portion of the H&D curve. Third, different films have peak contrast occurring at distinctly

different optical densities. For example, extended processed Microvision, standard processed Microvision, and extended processed MRE-1 film have contrast peaking at an optical density of about 2.0, while all other standard processed films have contrast peaking at optical densities of approximately 1.5.

Fourth, and most importantly for confirming our hypothesis, all mammography films operate at reduced contrast for optical densities below 1.2, with substantial reductions in contrast as optical densities fall below 1.0. This confirms that it is an inherent property of the film used for mammography that contrast is substantially reduced in any area of a film with an optical density below 1 to 1.2. This finding is independent of the film type used, and independent of whether standard or extended processing is used. Additional testing has confirmed that the use of sub-optimal processing conditions only exacerbate this loss of contrast.

2. Evaluation of Mammography System Performance

Our second hypothesis is that the AEC performance of many mammography units in current use contribute to the problem of obtaining adequate contrast in images of thicker, denser breasts. To test this hypothesis, we performed a compilation and analysis of data collected over the past three years (September 1992 to March 1995) in 177 standardized performance evaluations of 103 different clinical mammography units in use in Colorado. These data were collected by medical physicists from UCHSC who evaluated these units as part of the quality assurance component of the Colorado Mammography Advocacy Project (CMAP). CMAP includes a surveillance system to track the mammography results and follow-up of women receiving mammography in Colorado. Currently, the system includes over 150,000 women receiving mammography at over 60 facilities. A pre-requisite for a facility to participate in CMAP is that they must undergo an extensive technical evaluation of mammography performance and meet minimum standards at or above those set by the ACR Mammography Accreditation Program **[4]**.

Elements of these performance data relevant to this project include currently used technique factors and the optical densities that resulted for a range of breast thicknesses tested at each site. At each site, the technique factors settings are those used clinically for the stated breast thickness, assuming a 50%/50% fatty/glandular tissue composition. The systems were tested using 2, 4, and 6 cm thicknesses of BR-12 with 50%/50% fatty/glandular composition. The results for 4.2 cm thicknesses are for the RMI-156 phantom. The results of this data collection and analysis are summarized in **Table 1**, which gives means and standard deviations for technical factors and resulting optical densities, and in **Table 2**, which gives complete ranges for the parameters listed in **Table 1**.

These evaluation data indicate that there is a general trend toward the use of increasing kVp for increased breast thickness, but that the increase is insufficient. While the average exposure times are reasonable for 2-4.2 cm breast thicknesses (averaging

0.3 to 1.1 seconds), exposure times average 2.4 seconds for a 6 cm breast thickness, with a range that extends up to 6.5 seconds. At the same time, optical densities for 6 cm thicknesses are lower (averaging 1.21), with a range that goes down to 0.35. Note also the trend that as breast thicknesses increase, average glandular breast doses increase dramatically, with average glandular doses more than doubling for each 2 cm increase in breast thickness (**Table 1**).

To assess these trends in more detail, **Figures 3-5** show histograms of the exposure times (**Figure 3**), resultant film optical densities (**Figure 4**), and average glandular doses (**Figure 5**), for the 177 units at 2, 4, 4.2, and 6 cm thicknesses of phantom material. Most notable are the high proportion of units requiring exposure times over 2.0 seconds for 6 cm breast thicknesses (**Figure 3**), the high proportion of units with optical densities at 1.1 or below (the data bin at 1.0 includes optical densities up to 1.1), primarily for 6 cm breast thicknesses (with some at optical densities of 1.0 or less even for thinner breasts) (**Figure 4**) , and the high proportion of units delivering average glandular doses above 400 mrad for 6 cm breast thicknesses (**Figure 5**).

Particularly relevant to our hypothesis are the optical density data presented in **Figure 4**. These data indicate that a substantial fraction of units have AEC systems that deliver an average optical density of 1.0 or less, primarily for thicker breasts, but some even for 2, 4, and 4.2 cm thick breasts. These tests at 2, 4, and 6 cm thicknesses are performed using a homogeneous slab of breast equivalent material, so the AEC is tested with a uniform average tissue composition. In most breasts, tissue heterogeneities and inability of the technologist to place the AEC detector directly over the most glandular part of the breast, will yield optical densities in the glandular tissues of the breast that are even lower than those measured. This means that the contrast reduction in glandular tissues is likely to be even greater than that indicated by these measurements using uniform slabs of BR-12 material.

A factor contributing to the problem of lower optical densities for thicker (and denser) breasts, is the poor AEC tracking of many mammography units. Our site testing revealed that 54 of the 177 units (31%) had AEC performance that was inadequate to meet the standards established for consistency of optical densities in the ACR Mammography Quality Control Manuals **[4]**; namely, that optical densities be maintained with $\pm$ 0.3 of the average as breast thickness is varied from 2 to 6 cm. For each of the 54 units not meeting this standard, optical density was lower for thicker breasts.

3. Evaluation of Dose and Contrast Properties of a Single Film-screen Mammography System

Having established the reduction in contrast for lower optical densities due to the properties of film, and the tendency of at least 30% of existing mammography units to produce

significantly lower optical densities for thicker breasts due to inadequate AEC performance, we embarked on investigation of the individual factors that affect contrast, exposure time, and dose in film-screen mammography. This was done with the idea of developing a strategy for technique optimization on any film-screen mammography unit.

We have completely characterized entrance exposure and average glandular dose as a function of compressed breast thickness and composition for each choice of technique factors: target-filter combination and kVp. The mAs was selected under AEC mode to produce uniform optical densities and uniformity was verified to be within ± 0.2. Results are shown in **Table 3** for Molybdenum/Molybdenum (Mo/Mo) target/filtration, **Table 4** for Molybdenum/Rhodium (Mo/Rh) target/filtration, and **Table 5** for Rhodium/Rhodium (Rh/Rh) target/filtration.

Our results to date quantify the loss of contrast on tissue equivalent material at a specific breast thickness and composition (5 cm thick, 50%/50% composition) for various target filter combinations as a function of optical density (**Figures 6-8**) and kVp (**Figures 9-11**). These data indicate the strong dependence of contrast on optical densities, regardless of target-filter selection. This result is expected, since loss of contrast at lower ODs is due to the properties of mammography film, which remain unchanged in these tests. These data do indicate that there is a 10-20% contrast loss in going from a Mo/Mo to a Mo/Rh target/filter combination, and a 20-30% loss going from Mo/Mo to a Rh/Rh target/filter combination, keeping kVp or optical density matched. We have also quantitated the effect of altering kVp on exposure time to achieve the same optical density (**Figure 12**). These results indicate that each increase in kVp by 2 cuts exposure time approximately in half to obtain the same optical density, for a given target/filter combination. We are currently in the process of collecting corresponding data on the loss of contrast due to variations in OD and kVp for other breast thicknesses and compositions.

4. Future Work to be Performed

We are still in the process of collecting data on the effect of kVp and optical density on contrast and contrast-detail over the full range of breast thicknesses and compositions for all target-filter combinations. These data will be used to establish optimal radiographic techniques for the x-ray system, film-screen combination, and processing conditions of our system. These data will then be used to develop a generalized method of optimizing mammography techniques for any film-screen system.

After this generalized method of system optimization is developed, it will be tested on at least 20 film-screen systems in use in Colorado, using CMAP mammography facilities as trial sites. The last phase of this project is to quantify the improvement in image quality produced by this optimization method applied to clinical sites.

The results of site testing and analysis performed by Dr. Plott that are part of this project have been accepted for presentation at the 1995 Annual Meeting of the Radiological Society of North America. They will also be written up and submitted for peer-reviewed publication within the next three months.

CONCLUSIONS

We have validated the two initial hypotheses on which this project was based:

i) that the properties of mammography film have a major effect on image contrast in film-screen mammography, especially within fibroglandular tissues which are displayed, and

ii) that the technical performance of current mammography units leads to lower optical densities for thick and denser breast, due to the performance of the AEC systems on those units.

We have collected the dosimetry and exposure time data needed to optimize technique selection, and we are in the process of collecting the contrast and contrast-detail data necessary to complete this optimization work. This should lead to a complete optimization of film-screen mammography, in spite of the recognized technical constraints that have hindered the success of film screen mammography in thicker, denser breasts in the past.

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APPENDIX

Tables 1-5 appear on pages 14-17.

Figures 1-12 appear on pages 18-29.

Table 1. Imaging techniques, entrance exposures, and average glandular doses for 177 evaluations of 103 mammography units (Average ± Standard Deviation).

	2 cm	4 cm	4.2 cm	6 cm
kVp	25 ± 1	26 ± 1	26 ± 1	28 ± 2
mAs	22 ± 12	80 ± 37	98 ± 45	215 ± 131
Time (sec)	0.3 ± 0.2	0.9 ± 0.4	1.1 ± 0.4	2.4 ± 1.1
Optical Density	1.51± 0.36	1.39 ± 0.24	1.38 ± 0.44	1.21 ± 0.31
HVL (mm Al)	0.32 ± 0.03	0.33 ± 0.03	0.33 ± 0.03	0.35 ± 0.03
ESE (mR)	185 ± 92	777 ± 232	970 ± 260	2672 ± 977
Dose (mrad)	55 ± 21	136 ± 36	153 ± 39	329 ± 111

Table 2. Range of imaging techniques, entrance exposures, and average glandular doses for 177 evaluations of 103 mammography units.

	2 cm	4 cm	4.2 cm	6 cm
kVp	23 - 29	24 - 30	24 - 30	25 - 32
mAs	6 - 80	27 - 296	31 - 346	36 - 903
Time (sec)	0.1 - 1.7	0.3 - 3.3	0.3 - 3.3	0.4 - 6.5
Optical Density	0.85 - 2.80	0.83 - 2.25	0.81 - 2.16	0.35 - 2.40
HVL (mm Al)	0.24 - 0.41	0.28 - 0.42	0.28 - 0.41	0.29 - 0.42
ESE (mR)	69 - 980	298 - 1904	365 - 2217	847 - 6370
Dose (mrad)	21 - 184	58 - 278	64 - 306	109 - 770

Table 3

Average Glandular Dose as a Function of Breast Thickness, Composition and Radiographic Technique

Target/Filter -- Mo/Mo

Phantom Composition	Phantom Thickness (cm)	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose
100% Adipose (0% Glandular)	2	24	36.2	2	26	32.0	2	28	28.4	2	30	26.2
	4	24	87.0	4	26	70.5	4	28	60.2	4	30	53.9
	6	24	210.6	6	26	167.4	6	28	137.4	6	30	116.1

Target/Filter -- Mo/Mo

Phantom Composition	Phantom Thickness (cm)	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose
70% Adipose (30% Glandular)	2	24	43.3	2	26	37.3	2	28	27.3	2	30	30.0
	4	24	114.6	4	26	90.9	4	28	55.7	4	30	72.3
	6	24	315.4	6	26	245.8	6	28	123.8	6	30	155.4

Target/Filter -- Mo/Mo

Phantom Composition	Phantom Thickness (cm)	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose
50% Adipose (50% Glandular)	2	24	49.3	2	26	41.5	2	28	36.9	2	30	34.1
	4	24	144.6	4	26	108.1	4	28	87.4	4	30	74.2
	6	24	0.0	6	26	339.1	6	28	246.2	6	30	194.0

Target/Filter -- Mo/Mo

Phantom Composition	Phantom Thickness (cm)	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose
30% Adipose (70% Glandular)	2	24	53.7	2	26	45.9	2	28	39.7	2	30	35.8
	4	24	175.2	4	26	133.9	4	28	112.4	4	30	98.7
	6	24	0.0	6	26	433.2	6	28	317.0	6	30	231.2

Target/Filter -- Mo/Mo

Phantom Composition	Phantom Thickness (cm)	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose
0% Adipose (100% Glandular)	2	24	67.1	2	26	56.4	2	28	48.3	2	30	42.9
	4	24	243.5	4	26	191.3	4	28	147.4	4	30	119.4
	6	24	0.0	6	26	0.0	6	28	443.5	6	30	311.2

Table 4

Average Glandular Dose as a Function of Breast Thickness, Composition and Radiographic Technique

Target/Filter -- Mo/Rh

Phantom Composition	Phantom Thickness (cm)	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose
100% Adipose (0% Glandular)	2	24	26.1	2	26	25.6	2	28	26.2	2	30	27.5
	4	24	54.2	4	26	51.6	4	28	51.2	4	30	50.9
	6	24	119.3	6	26	117.2	6	28	117.8	6	30	115.6

Target/Filter -- Mo/Rh

Phantom Composition	Phantom Thickness (cm)	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose
70% Adipose (30% Glandular)	2	24	31.2	2	26	29.9	2	28	30.3	2	30	30.6
	4	24	73.9	4	26	68.7	4	28	66.1	4	30	63.4
	6	24	208.0	6	26	176.5	6	28	156.2	6	30	136.7

Target/Filter -- Mo/Rh

Phantom Composition	Phantom Thickness (cm)	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose
50% Adipose (50% Glandular)	2	24	35.5	2	26	33.4	2	28	33.2	2	30	33.0
	4	24	85.4	4	26	80.7	4	28	79.0	4	30	71.5
	6	24	259.9	6	26	221.8	6	28	196.2	6	30	184.5

Target/Filter -- Mo/Rh

Phantom Composition	Phantom Thickness (cm)	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose
30% Adipose (70% Glandular)	2	24	39.3	2	26	36.3	2	28	35.3	2	30	34.4
	4	24	118.4	4	26	96.4	4	28	94.9	4	30	91.6
	6	24	382.7	6	26	294.8	6	28	255.8	6	30	217.1

Target/Filter -- Mo/Rh

Phantom Composition	Phantom Thickness (cm)	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose
0% Adipose (100% Glandular)	2	24	49.5	2	26	43.0	2	28	39.8	2	30	36.7
	4	24	156.8	4	26	135.1	4	28	120.8	4	30	106.9
	6	24	0.0	6	26	451.6	6	28	389.6	6	30	321.8

Average Glandular Dose as a Function of Breast Thickness, Composition and Radiographic Technique

Target/Filter -- Rh/Rh

Phantom Composition	Phantom Thickness (cm)	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose
100% Adipose (0% Glandular)	2	24	0.0	2	26	0.0	2	28	0.0	2	30	0.0
	4	24	0.0	4	26	45.9	4	28	40.9	4	30	38.2
	6	24	0.0	6	26	100.5	6	28	85.0	6	30	75.4

Target/Filter -- Rh/Rh

Phantom Composition	Phantom Thickness (cm)	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose
70% Adipose (30% Glandular)	2	24	0.0	2	26	0.0	2	28	0.0	2	30	0.0
	4	24	0.0	4	26	55.1	4	28	50.4	4	30	47.3
	6	24	0.0	6	26	143.9	6	28	114.1	6	30	95.0

Target/Filter -- Rh/Rh

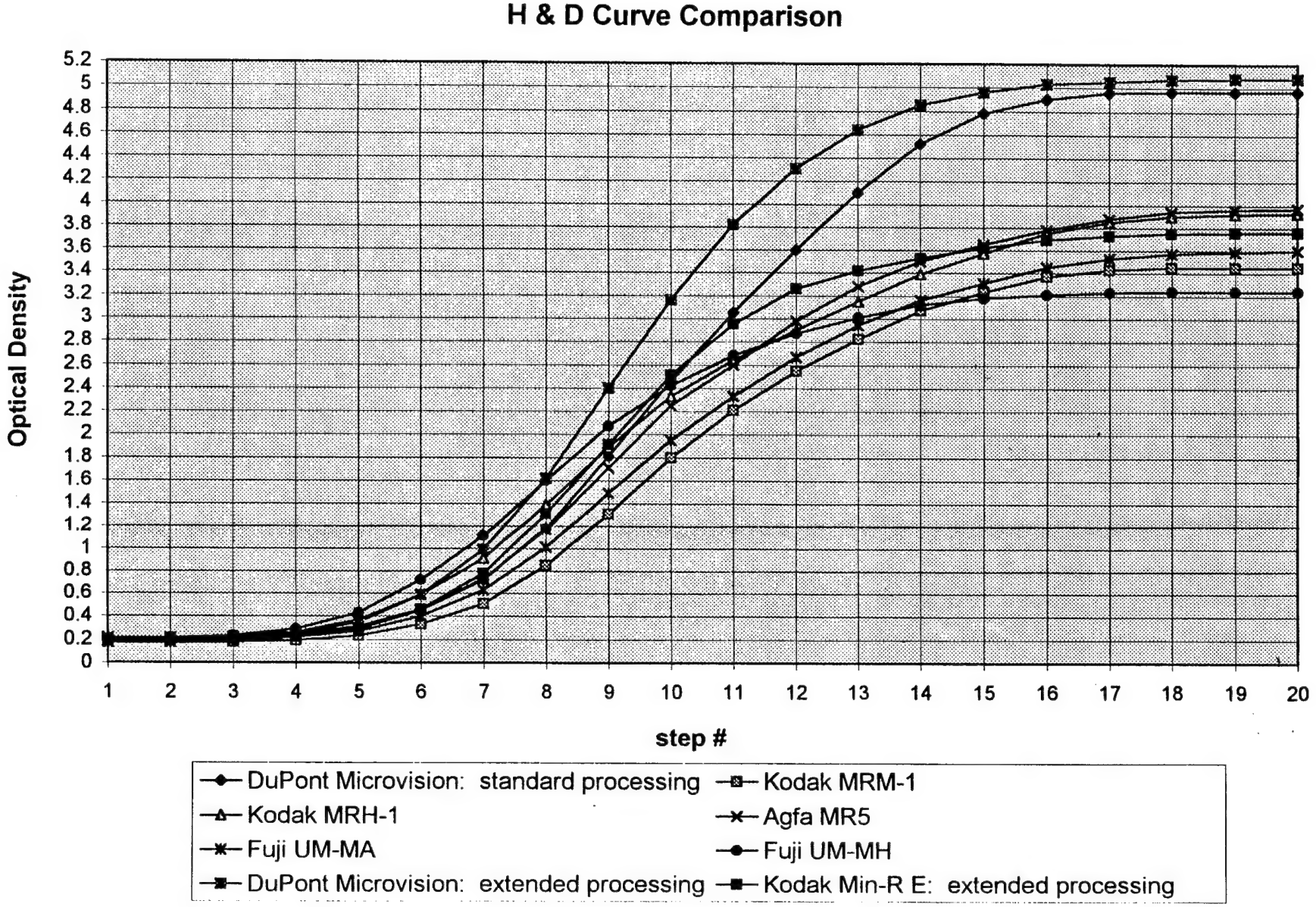
Phantom Composition	Phantom Thickness (cm)	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose
50% Adipose (50% Glandular)	2	24	0.0	2	26	0.0	2	28	0.0	2	30	0.0
	4	24	0.0	4	26	70.2	4	28	58.0	4	30	50.5
	6	24	0.0	6	26	178.3	6	28	143.2	6	30	120.4

Target/Filter -- Rh/Rh

Phantom Composition	Phantom Thickness (cm)	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose
30% Adipose (70% Glandular)	2	24	0.0	2	26	0.0	2	28	0.0	2	30	0.0
	4	24	0.0	4	26	80.0	4	28	68.1	4	30	60.0
	6	24	0.0	6	26	230.5	6	28	181.9	6	30	149.9

Target/Filter -- Rh/Rh

Phantom Composition	Phantom Thickness (cm)	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose	Phantom Thickness	kVp	Glandular Dose
0% Adipose (100% Glandular)	2	24	0.0	2	26	0.0	2	28	0.0	2	30	0.0
	4	24	0.0	4	26	107.8	4	28	86.3	4	30	73.0
	6	24	0.0	6	26	343.1	6	28	250.2	6	30	190.5


H & D Curve Comparison
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4.8
4.6
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Kodak MRH-1
Agfa MR5
Fuji UM-MA
Fuji UM-MH
DuPont Microvision: extended processing
Kodak Min-R E: extended processing

Figure 1

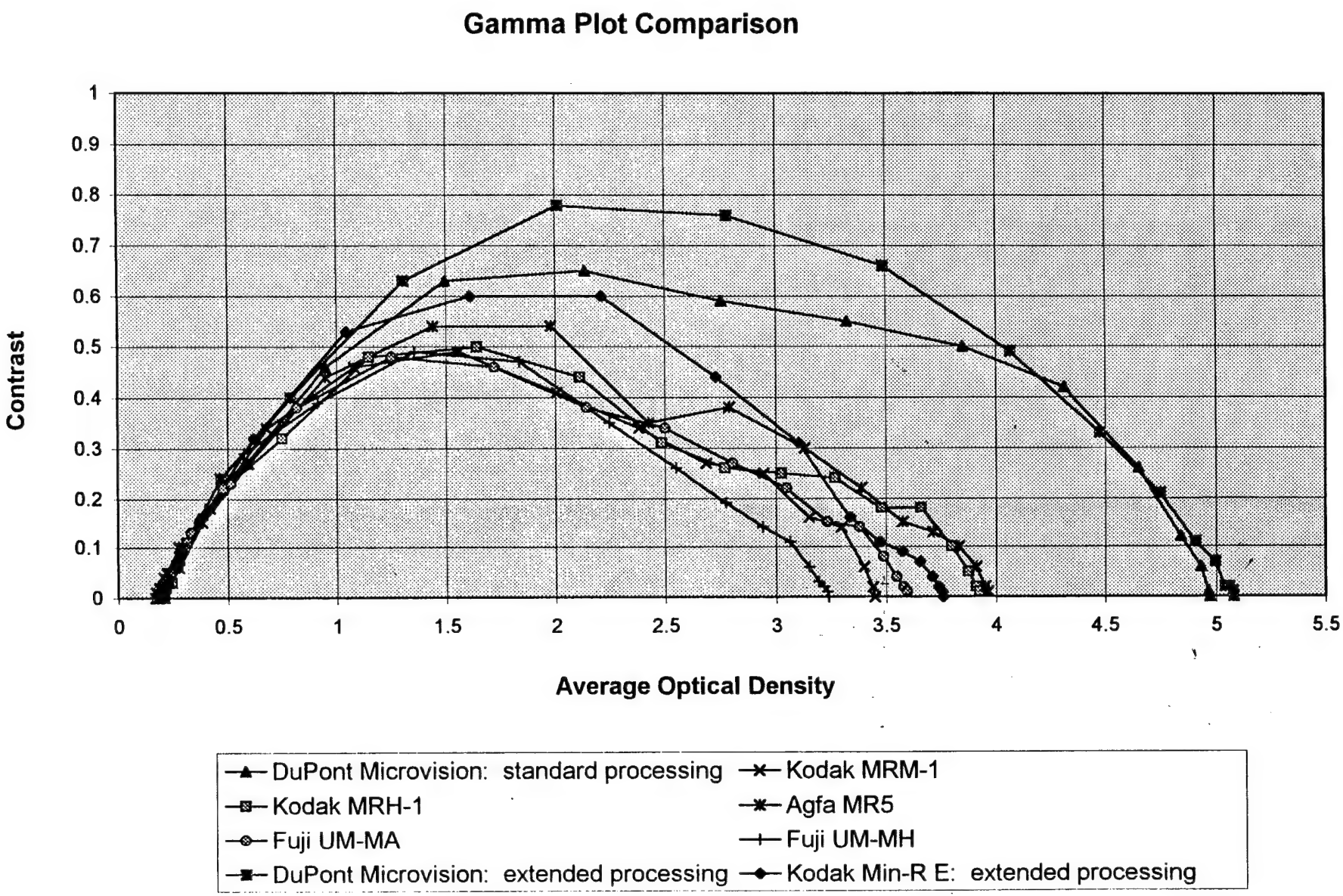
Gamma Plot Comparison
Contrast
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
Average Optical Density
DuPont Microvision: standard processing
Kodak MRM-1
Kodak MRH-1
Agfa MR5
Fuji UM-MA
Fuji UM-MH
DuPont Microvision: extended processing
Kodak Min-R E: extended processing

Figure 2

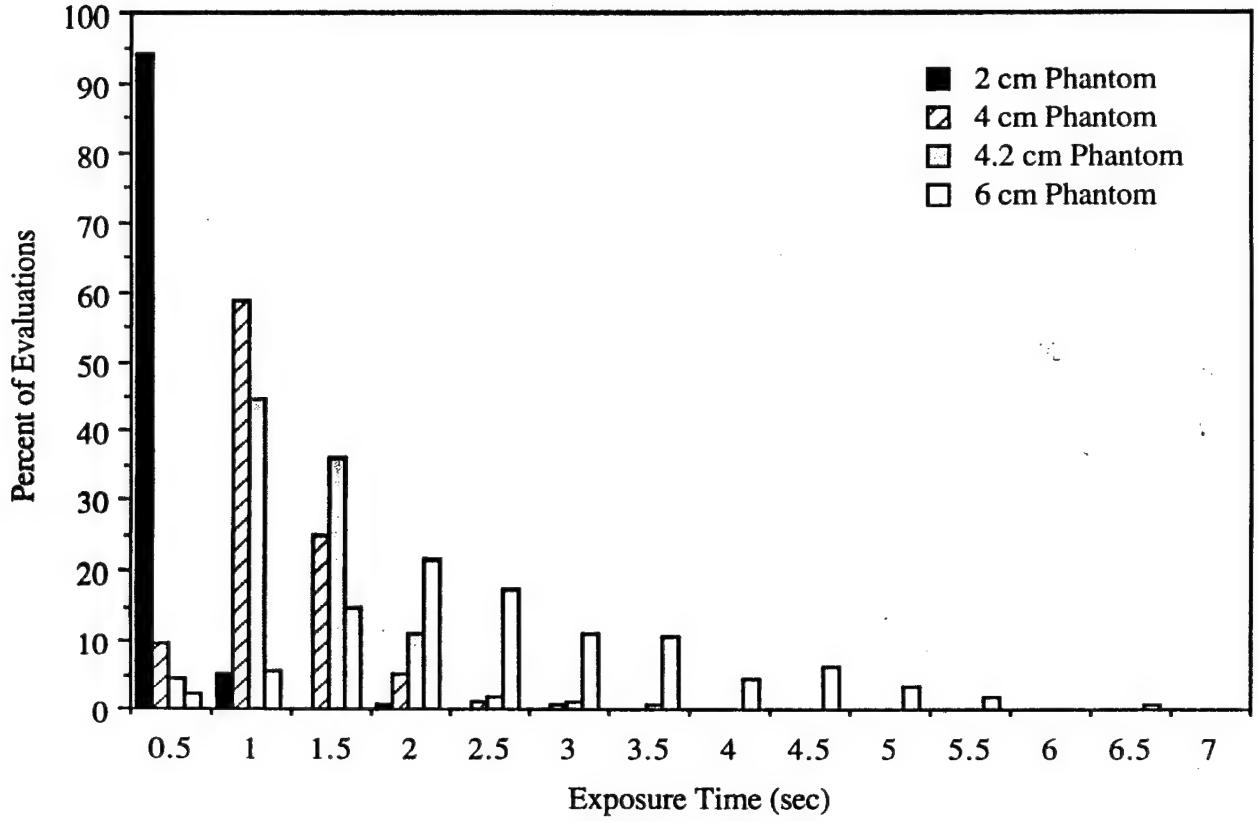

Figure 3. Exposure times of phototimed simulated breast (phantom) images (177 evaluations of 103 mammography units).

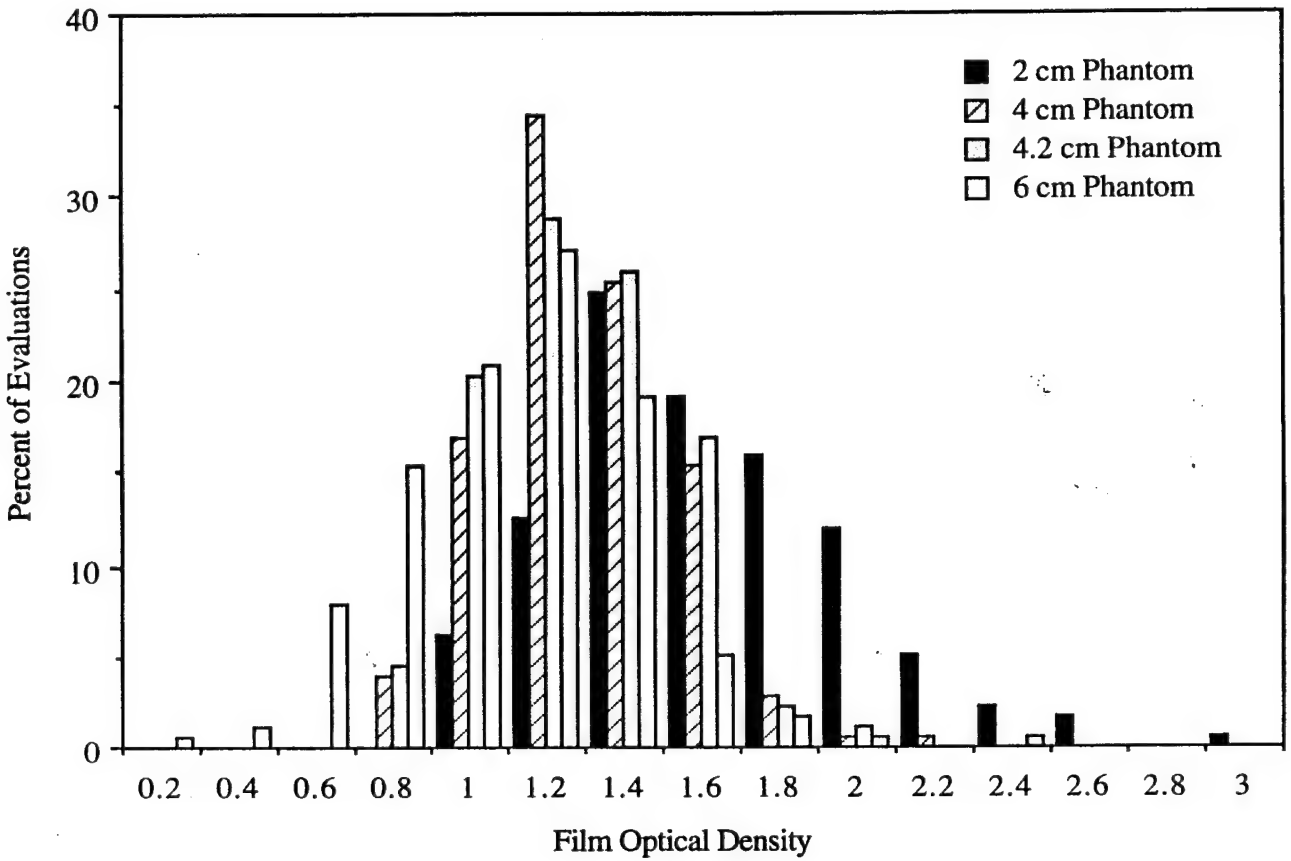

Figure 4. Film optical density of phototimed simulated breast (phantom) images (177 evaluations of 103 mammography units).

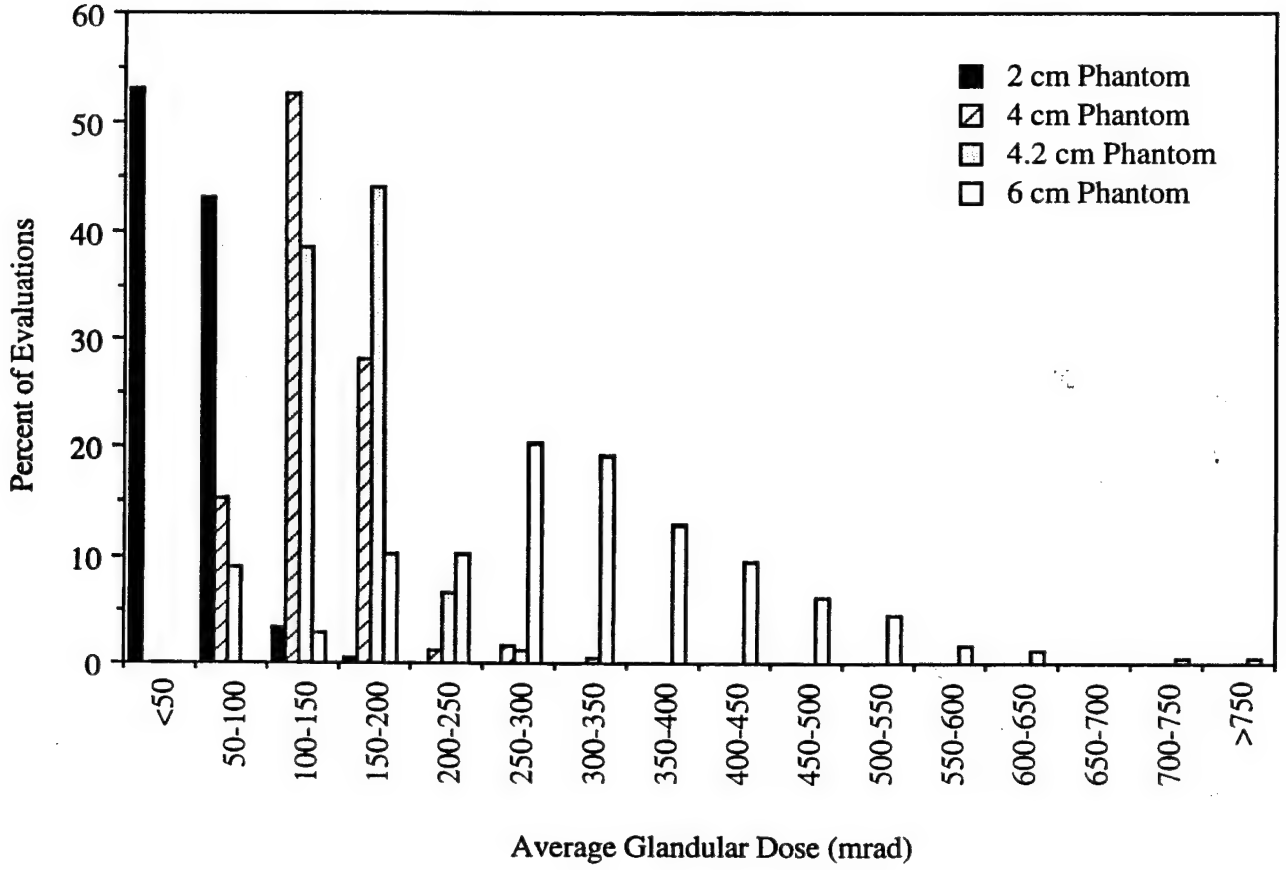

Figure 5. Average glandular dose as a function of simulated breast (phantom) thickness (177 evaluations of 103 mammography units).

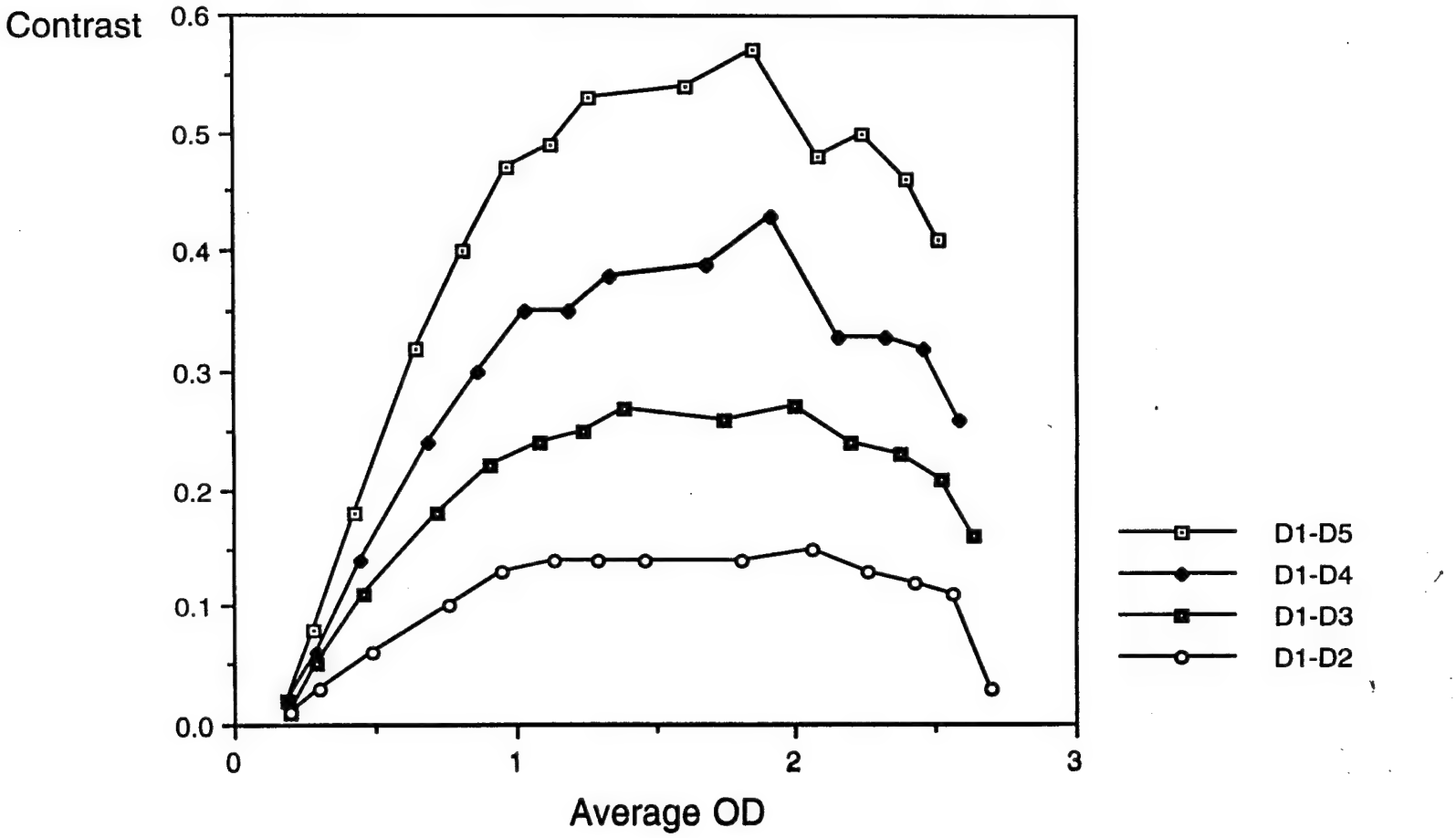
Mo/Mo: 26 kVp
Contrast
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
Average OD
D1-D5
D1-D4
D1-D3
D1-D2

Figure 6

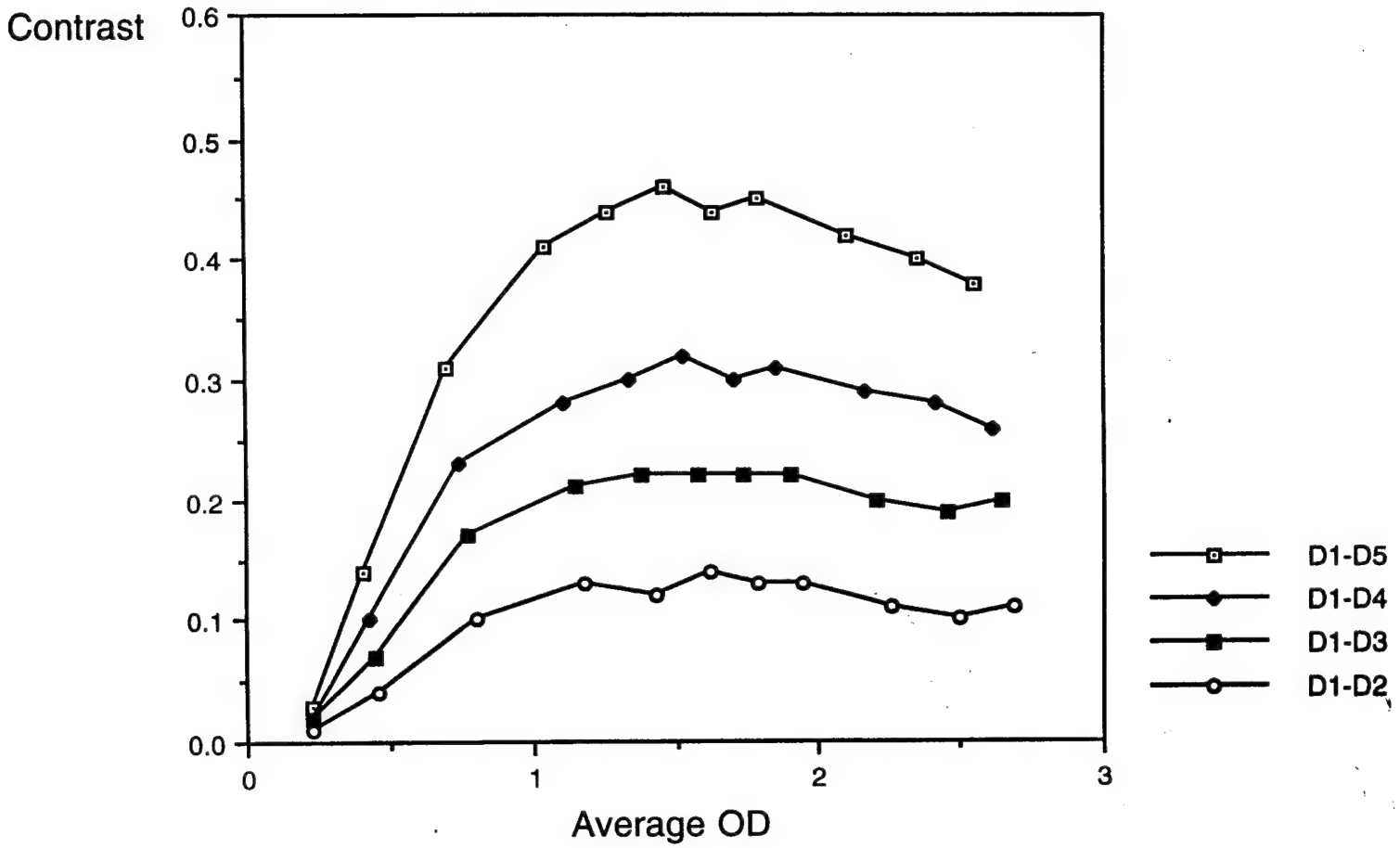
Mo/Rh: 26 kVp
Contrast
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
Average OD
D1-D5
D1-D4
D1-D3
D1-D2

Figure 7

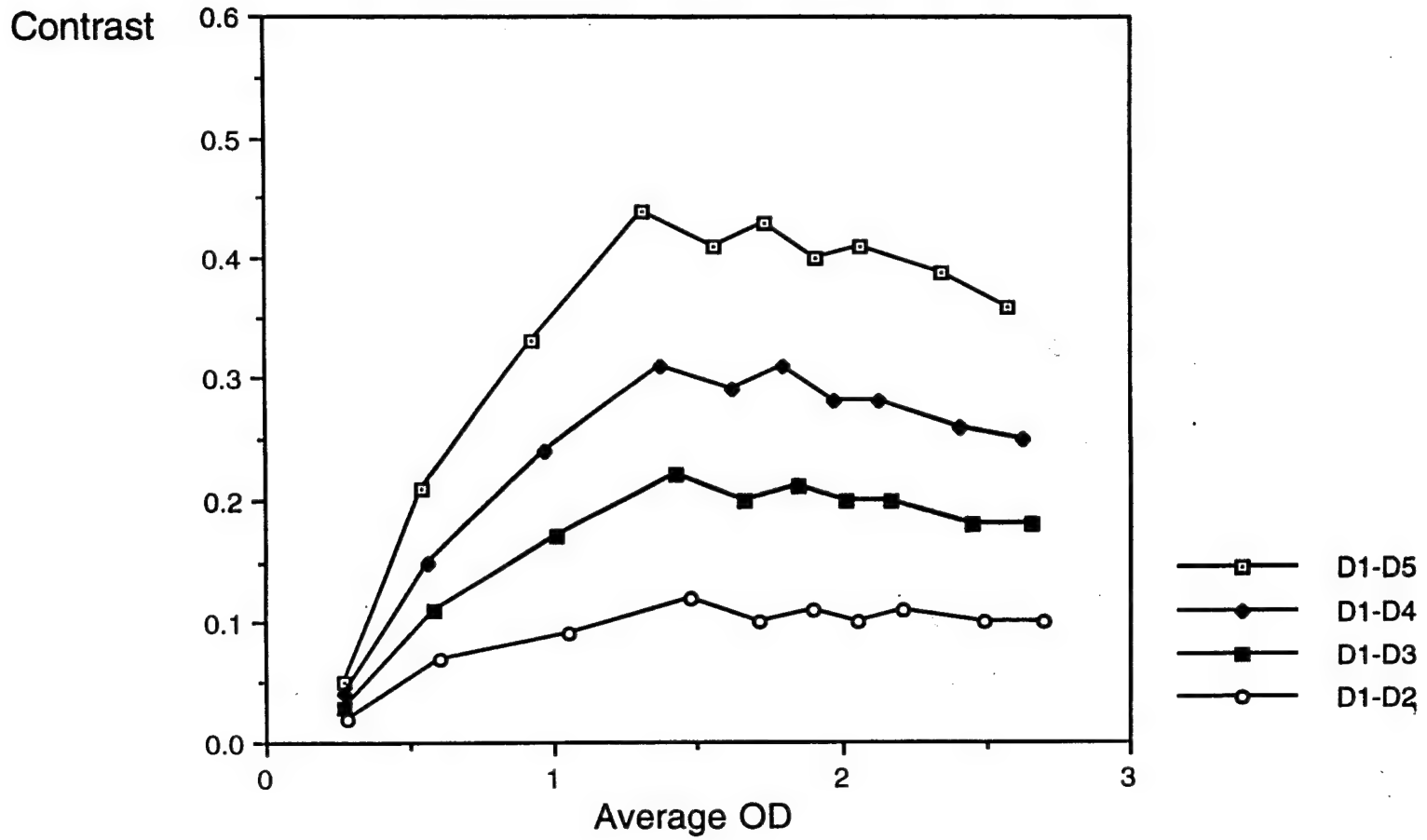
Rh/Rh: 26 kVp
Contrast
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
Average OD
D1-D5
D1-D4
D1-D3
D1-D2

Figure 8

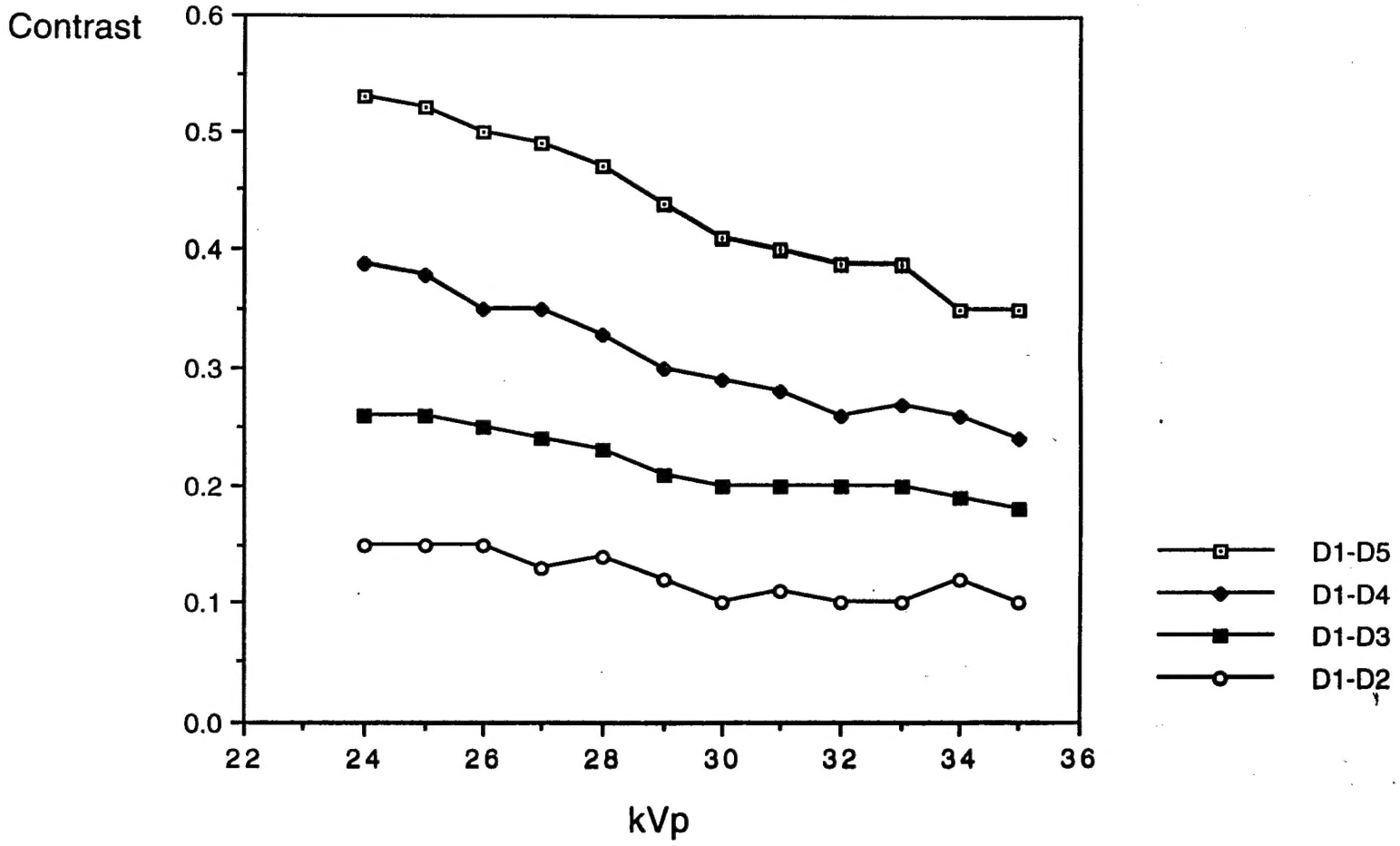
Mo/Mo: Background OD = 1.6
Contrast
0.6
0.5
0.4
0.3
0.2
0.1
0.0
22
24
26
28
30
32
34
36
kVp
D1-D5
D1-D4
D1-D3
D1-D2

Figure 9

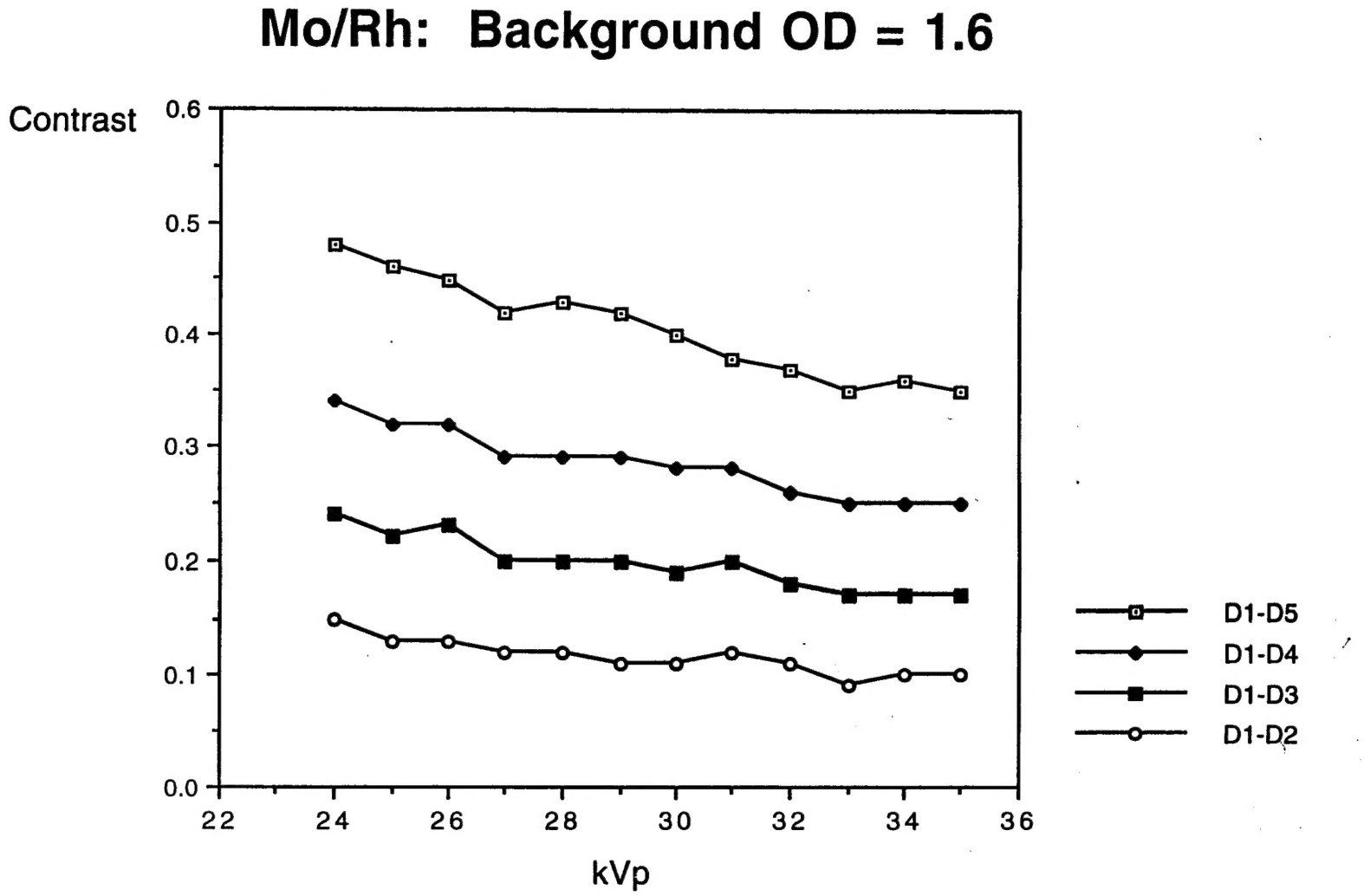
Mo/Rh: Background OD = 1.6
Contrast
0.6
0.5
0.4
0.3
0.2
0.1
0.0
22
24
26
28
30
32
34
36
kVp
D1-D5
D1-D4
D1-D3
D1-D2

Figure 10

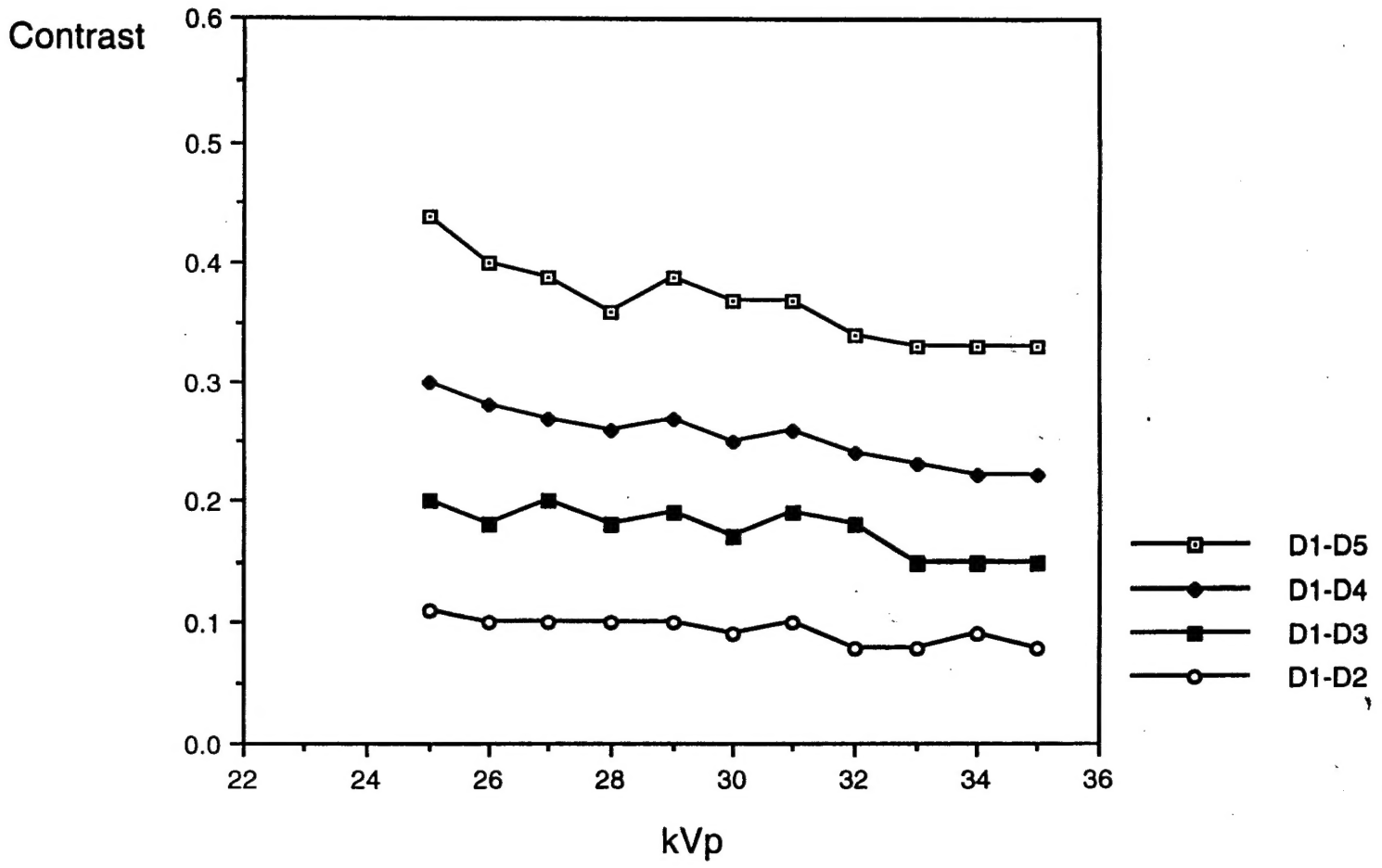
Rh/Rh: Background OD = 1.6
Contrast
0.6
0.5
0.4
0.3
0.2
0.1
0.0
22
24
26
28
30
32
34
36
kVp
D1-D5
D1-D4
D1-D3
D1-D2

Figure 11

AEC Mode
mAs versus kVp

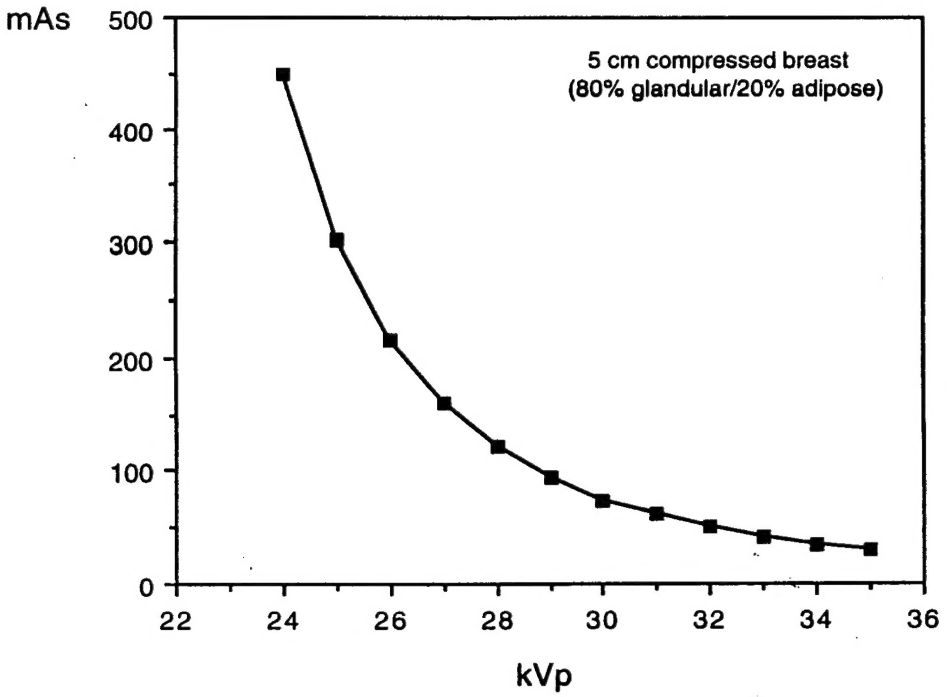

Figure 12